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ELECTRONIC DIRECT-CURRENT AMPLIFIERS

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The measurement and control of nonelectrical and electrical quantities is carried out primarily by electrical methods in which the quantities to be controlled are preliminarily transformed into electrical quantities by means of special converters or transmitting elements. The basic elements involved are the controlled quantities (mechanical displacement, AC voltage, DC voltage, pressure, temperature, etc.), the transmitting element (rheostat, RC differentiating circuit, RC integrating circuit, thermocouple, photoelement, etc.), and the electrical quantity at the transmitting element output (AC or DC voltage). The output parameter of a majority of contemporary transmitting elements is DC voltage. There is a tendency to measure even electrical parameters, such as phase, frequency, and power, by converting them to a DC voltage. This is necessary in cases where the measurement is made for control or regulation purposes.

The design of contemporary transmitting elements is such that their output voltage as a rule is low, their internal resistance is often very high, and their output power is low. Consequently, linear amplifiers with high amplification factors must frequently be used to supply power to the control devices.

In connection with Class C amplification, it should be noted that industry is producing special pentodes with a short grid characteristic, for example, the 6Zh11B. Class 0 operation is characterized by the fact that the tube operates in the region of grid current; a high series resistance R_g is included in the grid circuit. Since R_g is much greater than R_{ig} (where R_{ig} is the internal resistance of the tube between the grid and cathode), almost the entire signal voltage is across the resistance R_g. The voltage between the grid and cathode remains steadfastly at zero and is independent of the signal voltage. A current limiter is used when the following stage must react to some parameter other than amplitude, for example, phase or frequency.

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Variable-mu tubes can be used for automatic regulation of amplification or for obtaining a controlled resistance (the value of which depends upon the bias on the control grid) This method of control produces large nonlinear distortions when the signal amplitude is greater than one-tenth of a volt.

Such regulation may be accomplished by changing the screen grid voltage of a pentode or by operating on the tail of the characteristic curve for a triode. However, in the latter method, the plate current is low, as are the transconductance and the amplification factor. If it is necessary to obtain amplification which is variable within comparatively narrow limits (of the order of 10-30) and frequency distortion must be small for signals of the order of 0.5 volt, then a high-frequency pentode connected as a triode (screen gride connected with the plate) should be used instead of a variable-mu tube.

Distortion

Linear distortion is caused by reactive resistances (capacitive and inductive) in the amplifier circuit. In a DC amplifier these are interelectrode capacitances and the capacitance of the wiring. Phase distortion is a very important characteristic for amplifiers designed for automatic control. Such amplifiers often operate on a phase-detecting mechanism, a phase-correcting stage, a condenser motor, etc. Phase distortion is directly connected with transient distortions; therefore, one of these characteristics can be evaluated from the other. Transient distortions are most important in the techniques of pulse automatic control.

With regard to nonlinear distortions, a distortion factor of 5 percent or even up to 15 percent in special cases is permissible if the tube is operating a relay or an electric motor. However, for measurement amplifiers, a distortion factor of the order of only 0.05 percent can be tolerated. Also, when the amplifier is operating in a counting-computing device, the error introduced by the amplifier must not exceed plus or minus 0.05 percent.

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Direct-current amplifiers can be used for amplification of small DC voltages which are changing slowly. The main difficulty encountered in their design is the problem of decreasing null instability, which is a slow arbitrary change of the output voltage. [redacted]

For Class A cascade connection of several stages, a resistance coupling scheme (which includes a plate resistor as well as a divider R_1-R_2 from plate to ground, with grid input taken off the middle tap of the divider) can be employed between stages. The frequency response at high frequencies can be improved by shunting a resistor by a high capacitance. Another method is to use a double-tube circuit in which the bias on the second tube is several volts above that of the first tube because its cathode resistor carries, in addition to its own current, the current of a third tube whose grid has a positive signal applied from a plate-ground divider; the grid of the second tube is connected directly to the plate of the first tube. The plate of the second tube can then be applied directly to the grid of a fourth tube if another double-tube stage is used. The null instability for both this system and the cascade connection is quite large and they operate satisfactorily only if a regulated voltage supply is used.

The primary reasons for null instability are changes in the supply voltages, in the temperature of the cathode, and in the contact potential difference between the grid and the cathode (aging of the cathode). Even if all voltages on a tube were to remain constant, its plate current would still change with time; the most noticeable change takes place in the first 100 hours of operation. The input stage of a DC amplifier, as a rule, operates under conditions of low plate currents. Under these conditions, null instability is small and is easily compensated; the plate current is not governed by the 3/2 power law but follows (within certain limits) the exponential law. The characteristic curves of a group of tubes of the same type are quite different in scale although the form of the characteristic is retained.

Temperature instability due to a decrease in the filament voltage can be compensated by using special circuits with an additional triode or diode. Diode compensation is simpler but less precise; however, it is still approximately ten times better than for an uncompensated amplifier.

The mu-cascade, the parallel-balance cascade, and the asymmetric parallel-balance cascade can be used to eliminate null instability caused by a change in the plate supply voltage. Operation of the mu-cascade is based on the fact that the output voltage of the cascade will not depend upon a change in the plate supply voltage if the ratio of the coupling resistance to the grid bias resistance (in a modified resistance-coupled circuit) is equal to mu. This circuit reacts only to positive signals and the temperature instability is not compensated; only triodes for which mu is almost independent of the plate current can be used. The parallel-balance cascade is a tube bridge in which many sources of instability (slight change in the plate voltage, filament voltage, etc.) are compensated. The system is very stable and is used in high-precision followers. The asymmetric parallel-balance cascade is distinguished by the fact that the amplification of its input tube is greater than that of its second tube, which has a grounded grid. The circuit operates stably, but its maximum allowable signal is smaller than in the symmetric circuit.

In a cascade connection of parallel-balance circuits, the plates of the first stage are connected directly to the respective grids of the second stage; Class A operation is secured because the plate resistances in the first stage and the cathode resistance in the second are high. Small inductances in the plates expand the frequency response to $0.8 \cdot 10^6$ and higher. There is no parasitic coupling through the plate supply line because the total plate current of each stage is independent of its input signal. The circuit is very stable and reliable in operation.

The series-balance cascade has low instability. In this circuit, the tubes are connected in series and the output is taken from the plate of the first tube and the midpoint of the voltage divider from the plate of the second tube to ground.

Three-terminal DC amplifiers are used in circuits for modeling regulation systems, in counting-computing devices, etc.; their output voltage is equal to zero when no signal is present; they have a common input and output terminal and use a common B-plus line. /The circuit diagram, the amplification per stage, and the internal resistance of the stage, given for the following types of DC amplifiers -- symmetrical parallel-balance cascade, asymmetrical parallel-balance cascade, three-terminal parallel-balance cascade, three-terminal series cascade, three-terminal cascaded parallel-balance cascade, three-terminal cascaded series cascade, and a three-terminal series amplifier cascaded by interstage dividers -- are available [redacted] 7 If large capacitances are connected in three-terminal amplifier circuits, the frequency response of the amplifiers can be widened. The three-terminal parallel-balance cascade and the three-terminal series cascade are narrow-band amplifiers because their output capacitance is the sum of the capacitance of the plate supply to ground and the input capacitance of the following cascade. If the internal output resistance of the amplifier is low, it can deliver considerable power to a load. The least output resistance is obtained in repeaters, which will be taken up at some future date.

The differential amplifier (subtractor) is distinguished by the fact that its output voltage is proportional to the difference of two input voltages. If noises entering from the circuits of both signal sources are in phase, they will be attenuated a hundredfold even a thousandfold in the subtractor circuit. The output voltage of the subtractor is linear even for large input signals. Temperature instability is negligible. This circuit may also be used as a null indicator.

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